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Analysis of grain quality at receival

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Abstract: The major cereal grains – wheat, maize, and rice – undergo a series of stages between harvest and the food- or feed-processing plant, involving storage, overland transport, terminal storage and overseas shipment. At each transfer point, a document accompanies a grain consignment that pertains to its quality (class, purity, sanitation, and grade). Even at the first point of sale, known as receival, grain quality is viewed in terms of its export value. Each of the major grain exporting countries (Argentina, Australia, Canada, the European Union, and the United States) has developed quality standards. This chapter addresses these quality standards in the context of how a cereal lot is assessed at receival.

Key words: receival, country elevator, inspection, grade, class, contaminants, defects, sampling.

11.1 Introduction

The point of receival for grain marks the end of the line for the grower, but it marks the first point in the chain that takes grain from raw commodity to the first stage in processing and beyond – a chain that often includes the country elevator, an inland terminal elevator, a mill or refinery, and an export terminal. At each transfer point, a grain lot typically has documentation that asserts its quality. For the dominant grains such as wheat, maize and rice, each major exporting country has developed standards for grade and class. Administration of these standards is performed by either government (as in the United States and Canada) or private cooperative (as in Australia).

Because more than half of a country's production of a grain may be exported, it is the export potential that drives the need for its grain standards. And despite the fact that not all grain is required to undergo a country's official inspection (for example, domestic sales in the United States do not require it), it is these standards that become the yardstick by which grain quality is considered, even at the first point of sale.

This chapter starts by describing the official practices and standards for the some of the World's major grain exporting countries, namely Argentina, Australia, Canada, the European Union, and the United States. Because of the openly accessible and abundant information on US grain standards and procedures, the most extensive description of that country's system is provided. The remaining countries follow suit, with space given to features that make each country's system unique. However, it should be noted that there are many common factors among the standards of the major exporting countries. For each country or region, a table is provided that summarizes the official standard. The chapter emphasizes the grain type, wheat, because it is a common crop of export for these countries.

Following the description of the country systems, this chapter describes the procedures and equipment that are commonly used at receival points. It should be noted, however, that the practices are widely varying, especially because official inspection at receival points is not generally needed. The remainder of the chapter is devoted to the description of procedures and methods that either are in use at stages further along the market chain or are in the midst of development that may have application at receival. It concludes with the author's thoughts on future trends in quality assessment at receival.

11.2 The US grain inspection system

Wheat is grown throughout the contiguous region of the United States, with the preponderance for export grown in the central plains, ranging from Texas north and westward to the state of Washington. Maize has a similar wide region, but to the east of the wheat region. Grain exports are handled primarily through the ports at New Orleans, Louisiana and Portland, Oregon, with a small fraction shipped through the Great Lakes and St Lawrence River. Inland facilities consist of country elevators and large terminals. Generally, grain is delivered by truck to the country elevator, by train car to inland terminals and mills, and by train car or barge to terminal ports.

The licensing of inland facilities is administered by the USDA Farm Service Agency. The United States Warehouse Act of 2002 authorized the USDA to license operators of agricultural warehouses, such as grain elevators. This program is voluntary, with approximately 700 grain facilities (45% of US commercial space) having become licensed under this Act (USDA-FSA, 2008). Licensees agree to pay annual fees ranging from (January 1, 2006 values) \$155 [<150 000 bu (52 900 hL) capacity] to \$3680 [10 000 000 bu (3.52 million hL) capacity] and agree to comply with the Act's regulations. Among the requirements for obtaining a license is that the warehouse, depending on the commodity, has personnel who are qualified to weigh, sample, inspect, and grade the commodity. Although the program is voluntary (hence, giving it the designation as a 'permissive regulatory act', USDA-FSA, 2008), a warehouse may become delisted if it fails to comply. The purpose of the Act is sixfold:

(1) providing protection for depositors of agricultural products,
(2) establishing a uniform regulatory system for storing such products,
(3) providing confidence to financial markets on the integrity and acceptability of warehouse receipts,
(4) facilitating interstate and global commerce for the marketing of these products,
(5) providing safe storage of the products at reasonable rates,
(6) requiring operators to accept the products without discrimination.

The regulations for licensed warehouses state that US government standards for kind, class, and grade are used when such standards exist or, in the absence thereof, applicable state or municipal standards are used. Grain that is traded for domestic use does not have to receive 'official inspection'. For wheat, maize, and rice, the official US standards prevail. The large number of warehouses prevents federal inspectors from being stationed at each. Rather, inspection is performed by trained local personnel. Either due to an appeal brought on by a dispute between the grower and the elevator operator or by interest of the elevator operator, a lot may be examined by the nearest federal field office or federally licensed office for official inspection at a predetermined cost. In such cases, a split sample (2000 g minimum) is drawn and delivered to the inspection office. The USDA Grain Inspection, Packers and Stockyards Administration (GIPSA), and specifically the branch known as the Federal Grain Inspection Service (FGIS) is the government entity charged with official inspection. FGIS maintains a national service center in Kansas City, MO and 12 field offices throughout the contiguous states. Complementing these offices are delegated or designated State offices and designated private agencies (approximately 60 altogether, hereafter termed 'official agency' offices) that have been approved by GIPSA to perform official inspection.

In the United States, the primary receival stations for grain sale are the country elevators. The overwhelming majority of grain lots delivered to the country elevator undergo unofficial inspection by elevator personnel for pricing and binning decisions. Only grain at export terminals that is destined to be sold overseas is required to undergo official inspection.

A Quality Assurance/Quality Control (QA/QC) program is administered by GIPSA to keep inspection operations and equipment in alignment, from official agency through field office and on to a national technical services facility. Written agreements are established between each official agency and field office for quality monitoring. The agreement outlines quality factors specific to the locality that should be checked. For example, scab damage may be problematic in a particular region, such that the agreement will specify that at least one sample containing this condition be submitted to the field office every month for quality assurance. Additionally, samples from randomly selected lots are submitted on a daily basis for a check of some or all grading factors of an official inspection. A similar mechanism of written agreements between field offices and the national office is utilized, also with conditions for daily, monthly, and bi-monthly submission of check samples that are inspected by the national office's ultimate arbitrator, the Board of Appeals and Review (BAR). Time charts and graphs are developed and the data are statistically analyzed to determine whether official agencies are in alignment with their respective field office, and likewise between field offices and the BAR. Details of the USDA's quality assurance – quality control program are contained in GIPSA's Quality Handbook (USDA-GIPSA, 1996). Specific details of GIPSA's QA/QC program for NIR calibrations are found in Section 11.7.10. Starting in 2006, GIPSA began a program designed to evaluate grain quality from first point of sale and onward to determine how quality changes when the grain reaches the point of export (USDA-GIPSA, 2008a). Starting with sorghum in 2006 and soybean in 2007, each assessment program is intended to last at least five years, with slightly more than 1000 samples per commodity-year sent from elevator to a private or state agency for official grading. Because of the newness of this program, results are not yet available.

11.2.1 Official inspection example: wheat

This section summarizes the procedure for official inspection and standards for wheat in the United States. The standards undergo periodic review by GIPSA, with the last full review in the early 1990s, and the next review planned for 2008–2009 (USDA-GIPSA, 2008a). US wheat is categorized into six 'pure' classes: Durum wheat, Hard Red Spring (HRS) wheat, Hard Red Winter (HRW) wheat, Soft Red Winter (SRW) wheat, Hard White wheat (HWW) and Soft White wheat (SWW). There are also two hybrid classes, unclassed wheat and mixed wheat, which arise from wheat that is intentionally not identified by class or wheat that is not at least 90% pure with respect to its most dominant class. In each of the first six classes, five grades exist, starting with No. 1 as the highest in quality and progressing downward to No. 5 (USDA-GIPSA, 2006a). One additional grade exists, US Sample Grade, to catch the lots that do not meet the requirements for Grade numbers 1 through 5.

The following procedures are applicable to grain lots that undergo official inspection (USDA-GIPSA; 1995); however, these procedures are also applicable as guidelines for unofficial operations. From each load (i.e., lot) of grain delivered by truck to the country elevator, a composite sample is collected by means of sub-sampling in order to produce a quantity (2000–2500 g) that is representative of the lot. Sampling is usually accomplished by: (1) probing the truck, (2) a diverter-type mechanical sampler that intermittently catches grain from the exit stream of the truck, or (3) a cup-type or pelican sampling device that is manually used to catch grain in sets (two per truck) from the elevator's load-in system. These devices are described later in the chapter.

Before the inspection sample is divided or has dockage removed, the inspector will check for any unusual odors. This can even occur while the grain is still in the truck. Odors are grouped into three broad categories. Sour odors can arise from fermentation of the grain, insects, heated grain during respiration or an off-odor picked up from storage. Musty odors can similarly arise from heated grain and insect activity, but may also arise from molds and the dirt picked up during harvest operations. The last category, Commercially Objectionable Foreign Odors, consists of odors that are imparted to the stored grain from external sources. These include smoke, oil products, fumigant residue, insecticide, decaying animal and vegetable matter, skunk, and weed seed. Presence of a distinct odor from any of these three categories, with exception of garlic or smut odor, results in the assignment to the lowest grade, 'US Sample grade'. Before relegating a lot to this status, the work portion is exposed to air in an open container for 4 hours, and then re-evaluated. Other conditions that may be assessed on the wheat lot as a whole are heat, caused from excessive respiration (often accompanied by a sour or musty odor), and insect infestation. For the latter condition, stored grain pests of primary importance include the rice weevil, granary weevil, maize weevil, cowpea weevil, lesser grain borer, and the grain moth. With either condition, the elevator operator may choose to reject the lot.

It should be noted that all the 'tests' prior to dockage removal are performed by visual or olfactory analysis, with the exception of moisture content. Moisture content, reported on a wet matter basis, is measured using a Dickey-john Grain Analysis Computer (GAC, Model 2100, Auburn, IL), which is a capacitive device that has undergone an accreditation process by GIPSA. Approximately 350 g of grain is used by this instrument, which possesses separate internal calibrations for all of the major grain species of the United States.

Inspection prior to dockage removal is performed on the original sample that has been divided using a Boerner or equivalent device to produce a work sample of 1000–1050 g. Based on visual inspection of the work sample, the sample is checked for counts in excess of various threshold levels (in parentheses), including animal filth (2), castor beans (2), crotalaria seeds (3), glass (1), insect-damaged kernels (32), stones (4), and other foreign substances (5), such that an excessive count relegates the lot to sample grade status. GIPSA defines dockage as 'all matter other than wheat that can be removed from the original sample by use of an approved device ... Also, underdeveloped, shriveled, and small pieces of wheat kernels removed in properly separating the material other than wheat and that cannot be recovered by properly rescreening or recleaning' (USDA-GIPSA, 2004b). In the United States, the Carter Dockage Tester is used for dockage determination. The device consists of a an inclined grate, or 'riddle', and two sieves, such that when combined with aspiration and motor-driven shaking, a clean work sample, consisting of chiefly intact millable kernels, is separated from the 'dockage' material.

The dockage-free work sample (1000–1050 g) undergoes additional steps in the inspection procedure, starting with the determination of test weight (bulk density). Test weight is measured using a longstanding procedure of pouring the grain from a fixed distance into a one-quart (0.95 L) cylindrical kettle of standard dimensions until overflowing, striking the kettle rim clean of excess grain, and determining the weight of the kettle contents. With test weight determination completed, the entire amount of the work portion is recombined, visually examined for ergoty kernels, then successively split by a Boerner divider to produce subsamples for additional visual analysis. Smut is evaluated on a 250 g portion (from two divisions), while on another 250 g portion, the percentage by weight of shrunken and broken kernels is determined as those which pass through a 0.064 in (1.6 mm) by 0.375 in (9.5 mm) oblong-hole sieve. Foreign material and heat-damage are examined on a portion from a fourth division (approximately 60 g). Finally, after two additional divisions, a 15 g sample is carefully examined one kernel at a time by using a hand pick to move kernels from a main pile to auxiliary piles defined by damage type, foreign material, wheat of other class, or other condition. Kernel counts or weight percentages are then determined for each pile, whereupon a grade for the lot or sub-lot is issued. Details of the maximum allowable levels of the various conditions for each grade are shown in Table 11.1. Considering that a 15 g portion of wheat may typically consist of 300–500 kernels, with each kernel separately examined, this stage of the inspection procedure is time consuming, and can last 10–15 minutes for samples of border line grades.

11.3 The Canadian grain inspection system

Wheat is the most abundant export crop produced in Canada, capturing approximately 62% of the total tonnage of the cereals and oilseeds exported from the 2006–2007 crop year (CGC, 2007). For this reason, this section is primarily devoted to the issues of wheat quality. Until recently, Canada relied on their longstanding method of wheat variety release and regulation, known as kernel visual distinguishability (KVD). This system required newly developed varieties to resemble one another within the same wheat class. By law, all varieties of wheat grown and sold in Canada were required to

Table 11.1 Official Standard for US wheat [source: see USDA-GIPSA (2006a)]

Grading factors	Grades US Nos				
	1	2	3	4	5
Minimum pound limits of:					
Test weight per bushel					
Hard Red Spring wheat or White Club wheat	58.0	57.0	55.0	53.0	50.0
All other classes and subclasses	60.0	58.0	56.0	54.0	51.0
Maximum percent limits of:					
Defects:					
Damaged kernels					
Heat (part of total)	0.0	0.2	0.5	1.0	3.0
Total	2.0	4.0	7.0	10.0	15.0
Foreign material	0.4	0.7	1.3	3.0	5.0
Shrunken and broken kernels	3.0	5.0	8.0	12.0	20.0
Total[1/]	3.0	5.0	8.0	12.0	20.0
Wheat of other classes:[2/]					
Contrasting classes	1.0	2.0	3.0	10.0	10.0
Total[3/]	3.0	5.0	10.0	10.0	10.0
Stones	0.1	0.1	0.1	0.1	0.1
Maximum count limits of:					
Other material in one kilogram:					
Animal filth	1	1	1	1	1
Castor beans	1	1	1	1	1
Crotalaria seeds	2	2	2	2	2
Glass	0	0	0	0	0
Stones	3	3	3	3	3
Unknown foreign substances	3	3	3	3	3
Total[4/]	4	4	4	4	4
Insect-damaged kernels in 100 grams	31	31	31	31	31

US Sample grade is wheat that:
(a) does not meet the requirements for US Nos. 1, 2, 3, 4, or 5; or
(b) has a musty, sour, or commercially objectionable foreign odor (except smut or garlic odor) or
(c) is heating or of distinctly low quality.
1/ Includes damaged kernels (total), foreign material, shrunken and broken kernels.
2/ Unclassed wheat of any grade may contain not more than 10.0 percent of wheat of other classes.
3/ Includes contrasting classes.
4/ Includes any combination of animal filth, castor beans, crotalaria seeds, glass, stones, or unknown foreign substance.

be registered by the Canadian Food Inspection Agency (CFIA). This was leading to problems with varieties being classed into the same class but having vastly different functionalities. It was also hampering wheat breeders' efforts in developing new varieties. A line with special traits such as resistance to disease would not be certified for release if it did not meet the visual appearance requirement. Conversely, an unclassed variety could sneak into the Canadian market system, just by having the visual characteristics of one of the classes. An example of this was a train shipment in 2002 that contained an excessive level of non-registered US wheat that resulted in the devaluation of the lot to feed status, and the grain company's consequential loss of hundreds of thousands of dollars (CGC, 2003). Lastly, there has been the desire of growers to have high yielding non-milling varieties that can be used for feed or ethanol production.

On 1 August 2008, Canada's replacement to the KVD system became effective for all eight western wheat classes [Canada Western Red Spring (CWRS), Canada Western Amber Durum (CWAD), Canada Western Red Winter (CWRW), Canada Western Extra Strong (CWES), Canada Prairie Spring Red (CPSR), Canada Prairie Spring White (CPSW), Canada Western Soft White Spring (CWSWS), and Canada Western Hard White Spring (CWHWS)]. The new system carries the name, 'Variety Eligibility Declaration' or VED. With the new system, sellers are required to certify that a wheat lot consists of varieties that are on the approved list of varieties for that particular class. An additional class has been added to cover varieties for non-milling purposes, such as for ethanol production or for feed. While these varieties still require registration by the CFIA, the requirements for registration are limited to disease and agronomic variety considerations.

In addition to the nine western wheat classes, the Canadian Grain Commission (CGC) regulates and grades wheat grown in the eastern region of the country, though this wheat is primarily used for domestic consumption, with exports of eastern wheat accounting for less than ten percent of the tonnage of all Canadian wheat exported in the 2006–2007 crop year (CGC, 2007). Divided into eight classes [Canada Eastern Red (CES), Canada Eastern Red Spring (CERS), Canada Eastern Hard Red Winter (CEHRW), Canada Eastern Soft Red Winter (CESRW), Canada Eastern Amber Durum (CEAD), Canada Eastern White Winter (CEWW), Canada Eastern Soft White Spring (CESWS), and Canada Eastern Hard White Spring (CEHWS)], these wheats also have grading standards.

Although the grading of wheat is generally similar among the classes in terms of the procedures and equipment used, the allowable levels of contaminants and defects for each grade is class dependent (CGC, 2008), as seen in Table 11.2. The grading procedure is heavily reliant on human visual analysis by trained CGC inspectors, in which percentages by count or weight are assessed on specific conditions of contaminants (e.g., ergot, excreta, matter other than cereal grains, Sclerotinia, and stones), wheat of other classes, and damage (e.g., stained, immature, degermed, fireburnt, green or pink from immaturity, sawfly, midge, shrunken and broken, smudge and blackpoint, and sprouted). In western wheat, insect damage (usually sawfly or midge) is generally less common than heat- and frost-damage. Two to five unique grades exist for the western classes, with grade No. 1 in each class being of highest quality. Only three grades exist for each of the eight eastern classes. Both western and eastern classes generally have a bottom class designated as 'Feed' for lots that do not meet the lowest grade within each class. In addition to the visual analyses, the equipment-based devices for grading include test weight apparatus, and for some of the western classes,

Table 11.2 Official Standard for Canada Western Red Spring (CWRS) wheat [source: see CGC (2008)]

Grade name	Standard of quality: Minimum test weight kg/hl (g/0.5 L)	Variety	Minimum hard vitreous kernels %	Minimum protein %	Degree of soundness	Foreign material: Ergot %	Excreta %	Matter other than cereal grains %	Sclerotinia %	Stones %	Total %
No. 1 CWRS	75 (365)	Any variety of the class CWRS designated as such by order of the Commission	65	10	Reasonably well matured, reasonably free from damaged kernels	0.01	0.010	0.2	0.01	0.03	0.6
No. 2 CWRS	72 (350)	Any variety of the class CWRS designated as such by order of the Commission	No minimum	No minimum	Fairly well matured, may be moderately bleached or frost-damaged, reasonably free from severely damaged kernels	0.02	0.010	0.3	0.02	0.03	1.2
No. 3 CWRS	69 (335)	Any variety of the class CWRS designated as such by order of the Commission	No minimum	No minimum	May be frost-damaged, immature or weather-damaged, moderately free from severely damages kernels	0.04	0.015	0.5	0.04	0.06	2.4
No. 4 CWRS	68 (330)	Any variety of the class CWRS designated as such by order of the Commission	No minimum	No minimum	May be severely frost-damaged, immature or weather-damaged, moderately free from other severely damaged kernels	0.04	0.015	0.5	0.04	0.06	2.4
CW Feed	65 (315)	Any class or variety of wheat excluding amber durum	No minimum	No minimum	Reasonably sweet, excluded from other grades of wheat on account of damaged kernels	0.1	0.030	1	0.1	0.1	10

Table 11.2 Continued

Grade name	Standard of quality: Minimum test weight kg/hl (g/0.5 L)	Variety	Minimum hard vitreous kernels %	Minimum protein %	Degree of soundness	Foreign material: Ergot %	Excreta %	Matter other than cereal grains %	Sclerotinia %	Stones %	Total %
Grade, if specs for CW feed not met	Wheat, sample CW Account Light Weight					Wheat, Sample CW Account Ergot	Wheat, Sample CW Account Excreta	Wheat, Sample CW Account Admixture	Wheat, Sample CW Account Admixture	2.5% or less – Wheat, Rejected grade, Account Stones Over 2.5% – Wheat, Sample Salvage	See Mixed grain

Grade name	Wheats of other classes or varieties (*): Contrasting classes %	Total %	Artificial stain, no residue %	Dark, immature %	Degermed %	Fireburnt %	Fusarium damage %	Grass green %	Grasshopper, army worm %	Heated: Binburnt severely mildewed rotted, mouldy %	Total %
No. 1 CWRS	0.75	2.3	Nil	1	4	Nil	2.5	0.75	1	1 kernel per 1000g	0.05
No. 2 CWRS	2.3	4.5	5K	2.5	7	Nil	1.0	2	3	4 kernels per 1000g	0.4
No. 3 CWRS	3.8	7.5	10K	10	13	Nil	2.0	10	8	6 kernels per 1000g	1.0

No. 4 CWRS	3.8	7.5	10K	10	13	Nil	2.0	10	8	6 kernels per 1000g	1.0
CW Feed			2	No limit	No limit	2	5	No limit	No limit	2.5	2.5
Grade, if specs for CW Feed no met	Over 10% amber durum – Wheat, Sample CW Account Admixture		Wheat, Ample CW Account Stained Kernels			Wheat, Sample CW Account Fireburnt	Wheat, Sample CW Account Fusarium Damaged Over 10% – Wheat, Commercial Salvage			Wheat, Sample CW Account Heated	

				Shrunken and broken (**)			Smudge and blackpoint		Sprouted	
Grade name	Natural stain %	Pink %	Sawfly, midge %	Shrunken %	Broken %	Total %	Smudge %	Total %	Severely sprouted %	Total %
No. 1 CWRS	0.5	1.5	2.0	4	5	7	30K	10	0.10	0.5
No. 2 CWRS	2	5	5	4	6	8	1	20	0.20	1.0
No. 3 CWRS	5	10	10	4	7	9	5	35	0.30	3.0
No. 4 CWRS	5	10	10	4	7	9	5	35	0.5	5
CW Feed	No limit	No limit	No limit	No limit	13	No limit within broken tolerances	No limit	No limit	No limit	No limit
Grade, if specs for CW Feed not met					Sample Broken Grain					

[K] Number of kernel-sized pieces in 500 g.
(*) See working tolerance for "Wheats of other classes or varieties".
(**) See truncation rule for "Shrunken and broken".

an instrument for protein content determination (usually performed by NIR). Protein content is reported on a 13.5% moisture basis.

Grade standards are further defined for wheat that has reached a port terminal in anticipation of overseas shipment. Essentially, the grade criteria remain the same with additional requirements on the tolerable levels of broken grain, and slightly more stringent criteria on the total level of foreign material. The reason for the added stringency is to safeguard the cleanliness reputation of Canadian wheat.

Despite the movement away from the KVD system, western Canadian wheat is still under close regulation of the Canadian Wheat Board. New lines are required to undergo a series of crop performance trials in the three years leading up to release. During this period the line is grown in several locations, and its performance in terms of agronomic and disease factors, as well as quality, is monitored to make sure that the line is consistent with its intended wheat class. Although new varieties will no longer have to resemble their assigned class, the requirement to grow only registered varieties will still be in effect. Further, the need to declare the variety of each lot at receival will become even more important. During the planning period for the declaration system, two penalty systems were suggested for noncompliance of variety declaration: a legislated fine system for false declaration and a reliance on litigation through the courts. The second system has been favored. Given that the accuracy of varietal identification will be crucial in the declaration system, the CGC has been conducting research on rapid methods for variety identification. As of 2006, they were using protein electrophoresis and a DNA-based system on multiple runs of individual kernels, with additional research on adapting the DNA technology to ground grain to eliminate the need for multiple analyses (CGC, 2006).

Determination of dockage consists of starting with a representative portion (≥900 g) of an official sample, in which the portion is generated from a Boerner-type divider. Canada defines dockage as 'any material intermixed with a parcel of grain, other than kernels of grain of a standard of quality fixed by or under this Act for a grade of that grain, that must and can be separated from the parcel of grain before that grade can be assigned to the grain' (CGC, 2005). It includes wheat with long rootlets, unthreshed wheat heads, and material other than wheat removed by a No. 25 riddle. Also, dockage includes material removed by a No. 5 buckwheat sieve, material removed by aspiration, and soft earth pellets handpicked from a 'clean' sample upon operation of a Carter dockage tester. Unofficial samples (≥750 g) can also be assessed for dockage using the same procedure. After dockage removal, the 'cleaned' sample is analyzed for additional contaminants and damage in order to determine grade. In this case the percentages by weight are based on the cleaned sample. The amount of grain that undergoes visual inspection is dependent on the contaminant or damage condition under scrutiny.

The Canadian Wheat Board operates as a single-desk market. This type of system, in which the price at receival is determined by the Board, is designed to smooth out fluctuations in the market that could be caused by competing countries, weather-related problems in transportation, and railcar demurrage charges caused by delays in loading ships at port. While the price for each class and grade is determined by averaging over the season, the actual calculations are based on the spreads between classes and grades, thus ensuring that wheat lots of perceived higher quality, be it due to class or grade, will always receive higher payment than those of lower quality, regardless of the market prices at any specific time instant. Price spreads are generally determined by analysis of the selling prices of Canada's competitors, which most often are the US futures prices. The single-desk price pooling does not extend to the rail transportation costs associated with moving grain from the elevator to the nearest point of export. Because such costs are paid by the farmer, growers that are nearest to the ports are advantaged.

The Canadian Wheat Board is in charge of setting the prices for wheat at receival. The Board is also in charge of scheduling visits to rural inland elevators, so that growers are notified, typically a week in advance, as to when a train is stopping to collect grain from the elevators in a given area. Despite the fixed price on wheat at receival, a grower may shop around for the elevator in an area that provides the most favorable assessment of protein content and grade.

Official inspection of wheat by the Canadian Grain Commission is mandatory for wheat delivered to terminal elevators but is optional for wheat delivered to the primary elevator. Under Section 30 of The Canada Grain Act (CGC, 2005) official inspection for grain may be made at any place where provisions for inspection have been made. The CGC furnishes staff members to collect *official samples*, and defines these separately from unofficial samples, in which the latter group may be collected by non-CGC members. For official samples, the CGC specifies that a mechanical sampler be used unless the physical structure of the sampling location prohibits the use of a mechanical sampler. An official sample for grade and dockage assessment must be at least 1 kg in size, and depending on the location of collection in the market stream and the lot's next intended recipient, the sample is retained for a minimum period lasting from 20 days to six months. For unofficial sampling, the actual method of sampling varies with the elevator. For each load delivered, about 1–2 kg of wheat is drawn by one of three main techniques: a pneumatic probe driven into the truck bin, a manual scoop used during truck unloading, and in rare circumstances, a diverter sampler.

Although there are no requirements on the models of quality assessment instruments at the primary elevator, most elevators possess a Carter Dockage tester, sets of hand sieves, and a capacitive moisture meter. Further, most will also have an NIR instrument for protein content determination. Less abundant are elevators with mycotoxin test kits, such as those used in DON determination. The CGC provides ELISA-based DON testing on a mail-in basis, in which farmers or elevator operators pay $50 Canadian for each one-kilogram sample sent to a service center or regional office.

At some elevators falling number testing may be performed for evidence of sprouting, though falling number is not a grading criterion. Rather, sprouting for grade determination is assessed by visual examination. Recently, the CGC has been pilot testing the Rapid Visco Analyser as an indicator of pre-harvest sprouting, with the reasons of a shorter analysis time and use of less water compared to the falling number method.

11.4 The Australian grain inspection system

The marketing and inspection of wheat in Australia until quite recently has been overseen by AWB Limited, formerly the Australian Wheat Board (AWB). The 1989 Wheat Marketing Act (see Australia COMLAW, 2008) gave the AWB the authority to purchase wheat from growers. Two stipulations were given for mandatory purchase of the wheat by the Board for inclusion in the pool: 1) the Board was required to purchase the grain when tendered; and 2) the grain had to meet the Board's standards. Standards were divided into two broad categories, these being Receival Standards for binning and Receival Standards for payment. The inspection procedure was the same for both standards. The single desk role of the AWB with regard to the wheat pool expired on 30 June 2008. This change of transferring the responsibilities of overseas grain marketing (the fate of most of the country's harvest) was chiefly for the reason of enhancing Australia's competitiveness and improving profits for growers and downstream marketers. However, following some very mixed experiences during the 2008/09 harvest, the first conducted in a fully deregulated environment, it would seem that only the latter aim has been achieved to date. Effective 1 July 2008, a new government entity, Wheat Exports Australia (WEA), was established to regulate the export of bulk wheat from Australia through what is known as the Wheat Export Accreditation Scheme. The WEA is charged with regulating and overseeing the private companies that sell bulk wheat overseas. Much of the framework for how Australia will operate its new system is outlined in an April 2008 report to the Minister of Agriculture by a government-appointed body called the Industry Expert Group (DAFF, 2008). The report describes procedures for developing and promoting new varieties, establishing and maintaining standards, providing market support, and supplying information on production and exportation, and it describes the roles of the Grain Research and Development Corporation (GRDC), industry and government.

Though these changes have taken away much of the authority of AWB Ltd, their receival standards will continue in closely related form, as Grain Trade Australia, GTA, formerly the National Agricultural Commodities Marketing Association (NACMA) assumes this role vacated by AWB, essentially removing government from the business of establishing wheat receival standards. Therefore, the AWB practices for assessment of wheat grade and varietal group, last updated in 2007, are described below (NACMA, 2008). At the time of this writing, the GTA has been revamping grain standards for the 2009–2010 season and has solicited the industry for feedback on the proposed changes.

Typically each bin-load is probed in three locations with a vertical probe, drawing at least 3 liters in total, plus an additional liter for every 10 tonnes in the load. A half-liter subsample is used in screening and manual inspection. In parallel, a subsample is drawn for moisture content and protein content analyses by NIR spectroscopy. Although the particular NIR instrument models are not specified, permissible errors in accuracy are given, such as 0.38 percentage units of moisture for the average absolute deviation differences with respect to the AACC convection oven approved method 44-15A (AACC, 2000), and 0.40 percentage units for protein content difference with respect to a combustion nitrogen method. Test weight is measured on a portion before cleaning.

Contaminant inspection generally begins with an 'as received' half-liter subsample unless otherwise specified. Cleaning consists of placing the one-half liter subsample on a screening device equipped with a slotted 2.00 mm screen. Separate determinations are made for the percentages by weight of unmillable material below (through) the screen and above the screen after the device has been mechanically shaken 40 times. Additionally, the material through the screen is visually inspected again for contaminants and defects.

Fourteen categories of contaminants are defined: pickling compounds, chemicals not approved for grain, foreign seeds, ergot, objectionable material, other non-objectionable material, earth, sand, stored grain insects, earcockle, field insects, snails, loose smut, and bread wheat kernels in durum samples. Each category has permissible limits that are attached to a particular grade. Limits for certain categories, such as pickling compounds (chemicals added to grain as a seed treatment for planting purposes), have a nil tolerance level, such that detection of any amount, at any stage in the receival process (initial truckload, probe sample, half liter subsample, or any other sub-samples) places the lot above the threshold.

For defects, 14 categories are similarly defined, these being sprouted, stained, pink stained, dry green or sappy or frost distorted, heat damaged, field fungi affected, black field fungi affected, rotted, ball smut affected, insect damaged, grain drying influence, staining due to moist plant material, takeall affected, and non vitreous kernels (for durum wheat). For both contaminants and defects, the inspection procedure is conducted by human visual analysis, in which the half-liter subsample is screened (12.7 mm × 2.0 mm slots) and the 'overs' are examined for a period lasting from 30 to 60 seconds for typical lots, and up to 5 minutes for cases in which the category level requires quantification, whereupon a 300-grain wheat assessment tray is typically used. The time limit restrictions do not apply to quantification assessments for contaminants.

In addition to the manual visual inspection procedures for contaminants and defects, the methods and procedures for wheat grading include the following assessments: moisture by oven drying or NIR, protein by combustion or NIR, test weight, falling number, vitreous kernels in durum wheat by visual analysis or digital imaging, and bread wheat kernels in durum wheat by visual analysis. The wheat variety of a lot is declared at time of receival. Variety, in combination with knowledge of the production region (state) of growth, determines the varietal group, or marketing class. A NACMA standard for one class, Australian Prime Hard, is summarized in Table 11.3. In the event that a lot contains more than one variety, two scenarios are possible. The first is that the multiple varieties are of the same grade classification status, whereupon the variety of greatest preponderance is recorded for the load. In the second scenario, the varieties are of different grade classification status, which necessitates that the load be graded at the lowest grade classification of the varieties present, and the lowest variety is recorded for the load. This is also most important for the capture and allocation of end-point royalties, a small sum of money per tonne, set by the breeder for each new variety registered under the PBR scheme. Plant breeders' rights (PBR), also known as plant variety rights (PVR), are intellectual property rights granted to the breeder of a new variety of plant, which are used to fund ongoing varietal development.

Examples of funded projects by Australia's Grain Research and Development Corporation (GRDC) for incorporating new technologies into inspections, such as NIR spectroscopy beyond its traditional role of protein and moisture analysis, digital imaging, and electronic noses, are summarized in Reuss (2003). Using digital imaging as an example, suggested potential applications included variety identification, mold detection, detection of defects such as sprouting and blackpoint, and detection of insects and weed seeds; however, the application of this technology in Australia at that time was quite small, and continues as such today.

With the changes invoked in 2008 that diminished the authority of the AWB Ltd, other organizations have already been assigned or designated to be assigned the various roles of wheat varietal development, classification, and maintenance of standards. By recommendation of the Wheat Industry Expert Group (IEG), the GRDC will manage the varietal classification process through 2010. By definition, wheat classification is, 'the categorization of a wheat variety into a grade based on processing and end product quality' (NACMA, 2008). In 2007, NACMA agreed to take over the maintenance wheat standards starting in 2008, a task previously performed by the AWB. These standards reflect the consensus of the industry and have shown a small departure from the AWB standards, with one of the principle changes being a dropping of the two-tier grade system, such that NACMA will cover only the standards for binning purposes and not the standards for payment purposes. Further, GTA does not have the authority to approve each variety within a grade. This is the function of an interim two-tiered external organization,

Table 11.3 Standard for Australian Prime Hard wheat [source: see NACMA (2008)]

Commodity: Wheat Grade: APH2		Season: 2008/09 Standard Reference No.: CSG-100
Quality Parameter	Specification	Comment
Varietal Restrictions	Yes	APH varieties only
Protein Min (%)	13.0	N X 5.7 @ 11 % Moisture Basis (by Dumas method)
Protein Max (%)	n/a	
Moisture Max (%)	12.5	AACC Oven Method 44-15A
Test Weight Min (kg/hl)	74	Trade Certified Chondrometer
Unmillable Material Above the Screen Ma (% by weight)	0.6	Includes whiteheads (with grains removed), chaff, backbone, Wild Radish, Milk Thistle, or other seedpods. Excludes other contaminants where tolerances already exist.
Screenings Max (% by weight)	5.0	All matter passing through a 2.0mm slotted screen – 40 shakes in the direction of the slots using an Agitator
Falling Number Min (sec)	350	Falling Number results overrides the visual assessment for Sprouted grains

Defective Grains Max – (% by count, 300 grain sample [500 grain sample for WA], unless otherwise stated)

Sprouted	Nil	Frost Damaged	1
Stained, including Staining due to Moist Plant Material, of which;	5	Heat Damaged, Bin Burnt, Storage Mould Affected or Rotted (entire load)	Nil
– Pink Stained	2	Grain Infected with Ball Smut (entire load)	Nil
Field Fungi Affected, including Black Field Fungi Affected (count per half litre)	10	Take all Affected	1
Dry Green & Sappy	1	Insect Damaged	1
Over-Dried Damaged	Nil		

Foreign Seed Contaminants Max – (count of seeds in total per half liter, unless otherwise stated)

Type 1 (individual seeds)	8	Colocynth, Double Gees/Spiny Emex/Three Cornered Jack, Jute, Long Head Poppy, Mexican Poppy, Opium Poppy, Field Poppy, Horned Poppy, Wild Poppy, New Zealand Spinach, Parthenium Weed
Type 2	Nil	Branched Broomrape, Castor Oil Plant, Coriander, Crown Garlic/Wild Garlic, Darling Pea, Ragweed, Rattlepods, Starburr, St. John's Wort

Table 11.3 Continued

Commodity: Wheat Grade: APH2		Season: 2008/09 Standard Reference No.: CSG-100
Quality Parameter	Specification	Comment
Type 3a	2	Bathurst Burr, Bulls Head/Caltrop/Cats Head, Cape Tulip, Cottonseed, Dodder, Noogoora Burr, Thornapple
Type 3b	4	Vetch (Tare, Vetch (Commercial)
Type 3c	8	Heliotrope (Blue), Heliotrope (Common)
Type 4	20	Bindweed (Field), Cutleaf Mignonette, Darnel (Drake Seepd), Hexham Scent/Meliot (only acceptable if no tainting odour is present), Hoary Cress, Mintweed, Nightshades, Paddy Melon, Skeleton Weed, Variegated Thistle
Type 5	40	Knapweed (Creeping/Russian), Sesbania Pea, Patterson's Curse/ Salvation Jane
Type 6	10	Colombus Grass, Johnson Grass, Saffron Thistle
Type 7a	1	Chickpeas, Corn (Maize), Cowpea, Faba Beans, Lentils, Lupins, Peas (Field), Safflower, Soybean, Sunflower
Type 7b	50	Barley (2 & 6 row), Bindweed (Australian), Bindweed (Black), Durum (contamination of bread wheat), Red/Spring Feed Wheats (unlimited for Feed Wheat), Oats (Black/ wild), Oats (Sand), Oats (Common), Rice, Rye (Cereal), Sorghum (Grain), Triticale, Turnip Weed. Any other foreign seeds not specified in Types 1–7(a) or in Unmillable Material Above the Screen that remain above 2.0 mm screen following the Screening process.
Small Foreign Seeds (% by weight)	0.6	All foreign seeds not specified in Types 1–7(b) that fall below the 2.0 mm screen following the Screening process
Other Contaminants Max – (count per half litre, unless otherwise stated)		
Pickling Compounds (entire load)	Nil	Pickled grain
Chemicals Not Approved for Grain (entire load)	Nil	Residues of any chemical not approved for wheat, or used in contravention of the labeled instructions
Ergot Ryegrass (length in cm)	2.0	Length of all pieces present aligned end on end
Ergot Wheat	1	

Live Stored Grain Insects & Pea Weevil (entire load)	Nil	
Dead Stored Grain Insects	5	
Dead Pea Weevils	3	
Earcockle	10	
Field Insects – Sitona Weevils	10	Dead or alive
Field Insects – All others	3	Dead or alive
Snails	1	Dead or alive
Loose Smut	3	
Sand	20	Individual grains
Earth	1	5 mm max in diameter
Objectionable Material (entire load)	Nil	Presence of meat meal, blood meal, fish meal, poultry offal meal, or other animal proteins. Sticks (>1 cm in length and 0.5 cm in diameter), stubble (>3 cm in length and 1 cm in diameter), stones (>2 mm in length and/or diameter), glass, concrete, metal, animal excreta, animal carcasses, tainting agents or any other commercially unacceptable contaminant, smell or taste.
Other Non-Objectale Material (% by weight)	0.1	Fine material (e.g. earth, dust and materials), pieces of snail shell (<half), pieces of stored grain insects and sticks (<1 cm in length and 0.5 cm in diameter)

which will oversee the variety classification process until the end of 2010. The operational tier is the Australian Wheat Variety Classification Panel AWVCP, comprising five independent wheat quality experts appointed by the GRDC in early 2009, and managed by BRI Research. It will meet four times annually and will classify all lines submitted to it by the nation's wheat breeding organizations. It will be overseen by the Wheat Classification Council, which will comprise a range of industry stakeholders (breeders, traders, marketers, domestic users) plus some technical experts, which, in light of any changes in market direction, competitor activity or food consumption trends, will review the Classification guidelines and make appropriate changes as necessary. The AWVCP will classify all new lines and prospective varieties into one of nine major marketing classes [Australian General Purpose (AGP), Australian Hard (AH), Australian Durum (ADR), Australian Prime Hard (APH), Australian Premium White (APW), Australian Standard White (ASW), Australian Noodle (ASWN), Australian Feed (FEED), and Australian Soft (SOFT)] depending on the geographical region (Queensland, Northern New South Wales, Central New South Wales, Southern New South Wales, Victoria, South Australia, and Western Australia) that a variety is grown. This means that a specific variety that is grown in one region may be assigned to a different varietal group than the same variety grown in another region. The purpose of such grouping is to categorize the wheats by similar quality characteristics suited for particular end product uses. GTA's role in overseeing the receival standards is considered to be ongoing, in which standards will be examined annually and changed as needed.

11.5 The European Union grain inspection system

Although it is not apparent that national rules are imposed on cereals sales at first point of sale in the EU, there does exist a price support or 'intervention' system for some of the major species, including durum wheat, common wheat, barley, maize, and sorghum (EC, 2008). Hence, these cereals that are taken over by intervention agencies must meet standards ratified by the Commission of the European Communities (EC). The standards address many of the same concerns of Australia, Canada, and the United States, namely damaged grain (broken, shriveled, discolored, overheated, sprouted, decayed, and insect-damaged), contaminants (extraneous seeds, husks, ergot, dead insects and insect fragments, other cereals, and extraneous matter), maximum moisture content, minimum protein content (durum and common wheat), and test weight (Table 11.4). As with the standards of the other exporting countries, the EC standards for contaminants and defects are reliant on human visual analysis. Additional criteria include a minimum falling number (durum and common wheat) and Zeleny sedimentation volume (durum only).

Table 11.4 European Community standard for grains in intervention program [source: see EC (2008)]

	Durum wheat	Common wheat	Barley	Maize	Sorghum
A. Maximum moisture content	14.5%	14.5%	14.5%	13.5%	13.5%
B. Maximum percentage of matter which is not basic cereal of unimpaired quality:	12%	12%	12%	12%	12%
1. Broken grains	6%	5%	5%	5%	5%
2. Impurities consisting of grains (other than indicated at 3) of which:	5%	7%	12%	5%	5%
(a) shriveled grains				–	–
(b) other cereals	3%		5%	–	–
(c) grains damaged by pests					
(d) grains in which the germ is discolored			–	–	–
(e) grains overheated during drying	0.50%	0.50%	3%	0.50%	0.50%
3. Mottled grains and/or grains affected with fusariosis of which:	5%	–	–	–	–
– grains affected with fusariosis	1.5%	–	–	–	–
4. Sprouted grains	4%	4%	6%	6%	6%
5. Miscellaneous impurities (Schwarzbesatz) of which:	3%	3%	3%	3%	3%
(a) extraneous seeds:					
– noxious	0.10%	0.10%	0.10%	0.10%	0.10%
– other					
(b) damaged grains:					
– grains damaged by spontaneous heating or too extreme heating during drying	0.05%	0.05%			
– other					
(c) extraneous matter					
(d) husks					
(e) ergot	0.05%	0.05%	–	–	–
(f) decayed grains			–	–	–
(g) dead insects and fragments of insects					
C. Maximum percentage of wholly or partially piebald grains	27%	–	–	–	–
D. Maximum tannin content ([1])	–	–	–	–	1%
E. Minimum specific weight (kg/hl)	78	73	62		–
F. Minimum protein content ([1]):					
– 2002/03 marketing year and onwards	11.5%	10.5%			
G. Hagberg falling number (seconds)	220	220			
H. Minimum Zeleny index (ml)	–	22	–	–	–

([1]) As % of dry matter.

11.5.1 United Kingdom

In the United Kingdom, the Home-Grown Cereals Authority (HGCA) is a non-profit cooperative that works in conjunction with the national government to establish industry policies for production, distribution, and processing of cereals. The HGCA released a white paper in 2004 that provided outlines for establishing standards for grain testing laboratories in the UK (HGCA, 2004). Although such proposed standards are not necessarily targeted for the first point of sale, but rather for analytical laboratories servicing the cereals industry, the listed items are indicative of the perceived importance of quality factors in the UK. From this paper, the two main commodities of interest are wheat and barley. For wheat, the following tests are recommended: moisture content, test weight, protein content, falling number, and hardness by SKCS (single kernel characterization system – see Martin *et al.*, 1993). For barley, the tests include nitrogen content, moisture content, test weight, germinative capacity, and a sieving profile.

In 2004, the HGCA Exports group released a branding system for UK wheats to be sold on the export market, which represented almost 20% of production. Two export classes were established: UKP and UKS. UKP is a blend of semi-hard varieties for use in breadmaking and UKS is a blend of soft extensible varieties for use in biscuit making or in blending with hard high protein wheats. The HGCA maintains a list of the varieties acceptable for classification into UKP or UKS. Additionally, these classes are defined by their typical ranges for protein content (dry matter basis, UKP = 11–13%, UKS = 10.5–11.5%) and Alveograph parameters ($W \geq 170$ for UKP, ≤ 120 for UKS; $P/L \leq 0.9$ for UKP, ≤ 0.55 for UKS).

11.5.2 France

The other major producer and exporter of cereals in Europe is France. In fact, France's wheat export tonnage in the 2002–2003 crop year was second only to the United States, with the north African countries being the largest buyers of French wheat. The French system of wheat classification is somewhat similar to the UK's, but with four instead of two classes. The four classes, designated E (highest quality), 1, 2, and 3, have cutoffs for protein content (by combustion), Alveograph W, and falling number. For example, wheat of class E must have a protein content > 12%, Alveograph W > 250, and a falling number > 250 s. This is in contrast with Class 3, in which protein content < 10.5% and there are no specifications for W or falling number.

11.6 The Argentine grain inspection system

The development and implementation of quality standards for wheat and maize in Argentina is less advanced than other major exporting countries, such as Australia, Canada, and the United States (Table 11.5). The government's role

Table 11.5 Official standard for Argentine bread wheat [source: see Argentine Wheat (2008)]

Hard type wheat admits as maximum 5% of semihard varieties

Grade	Minimum test weight per hectoliter (kg/hl)	Percent maximum limits of								Sweet clover seeds/ 100 g
			Damaged kernels							
		Foreign material (%)	Heat damaged kernels (%)	Total (%)	Smutty kernels (%)	Yellow berry kernels (%)	Shrunken and broken kernels (%)	Insect bored kernels (%)	Moisture (%)	
1	79.0	0.20	0.50	1.00	0.10	15.0	0.50			
2	76.0	0.80	1.00	2.00	0.20	25.0	1.20	0.50	14.0	8
3	73.0	1.50	1.50	3.00	0.30	40.0	2.00			

Living insects and/or arachnids free for all grades.
Protein content: basis 11% (moisture basis of 13.5%).

in quality inspections ceased in the late 1980s with the private sector assuming quality duties, leaving federal inspectors with duties of issuing phytosanitary certificates and conducting fumigation and stowage examinations. Leading up to 2004, quality standards were predominately based on sanitation issues, despite the fact that Argentina has been one of the top five exporters of wheat. While most exported product has gone to other South American countries such as Brazil, Bolivia, Paraguay, Uruguay, and Chile (Frank, 2005), both Argentine and Brazilian maize have attracted interest in European countries that wish to import non-transgenic varieties. Expansion of its wheat export market to countries outside of this region has been hampered by the perception of the low quality and variability in quality of Argentine wheat.

Traditionally, Argentine wheat has been stored and handled on an FAQ (fair average quality) basis with all deliveries that meet the physical grade specifications binned together. This results in a fairly non-descript bulk which varies somewhat due to seasonal conditions and varietal composition. Since 1998 there has been a coordinated effort to introduce a variety classification system in Argentina, with a view to segregating the better quality varieties from the bulk, and establishing quality premiums in the domestic market. With enactment of a national resolution (No. 334) establishing a wheat quality program known by the acronym PRONACATRI (Programa Nacional de Calidad del Trigo), release of wheat germplasm by quality grouping has been practiced since 2004. This is being driven by the Instituto Nacional de Tecnología Agropecuaria (INTA, the government's agricultural research organization), grower groups, and some private storage operators, and it is now gaining acceptance with an increasing number of operators offering premiums for specific varieties. All new varieties are required to pass through a coordinated trial program to enable them to be classified, they must be registered with the National Registry of Varieties, and the commercialization of new and certified seed must be authorized by Argentina's Secretariat of Agriculture, Livestock, Fishing and Food (SAGPyA). All-in-all, there is a fair amount of administrative control throughout the system.

Varieties are classified into three groups using seven test variables (from most to least important, based on their impact on processing quality and value): Alveograph strength (W), loaf volume, protein and gluten content, flour yield-to-ash content ratio, Farinograph dough stability, wet gluten content, protein content, and test weight. The weighted sum of these variables, with each defined using a 0-to-9 scale, produces what is known as a Quality Index for bread wheat for each variety (SAGPyA, 2004). Group 1 cultivars are extra strong wheats suitable for blending and baking. This group represented 29% of the wheat in a national survey for 2007, the most recent year reported (SAGPyA, 2007). Group 2 cultivars are wheats adapted to traditional methods of baking (artisan breads of more than 8 hours of fermentation time). These comprised about 47% of the wheat in the 2007 survey. The last group, Number 3, are cultivars suitable for direct methods of baking (artisan breads of less than 8 hours of fermentation time). This group represented only 16% of the wheat in the 2007 survey.

Limitations in storage facility infrastructure for segregation of wheat and corn by quality have also contributed to a less elaborate system for quality assurance than the other exporting countries. Inland movement of grain is primarily by truck and to a lesser extent by rail, with limitations in capacity at non-port facilities. Depending on state law, grain inspection may be required while the grain is in transit to the export terminal, primarily for the purpose of identifying the presence of transgenic maize varieties. However, popularity in the use of 200-tonne silo bags has grown in the past ten years, with approximately one-fifth of the country's annual grain production being accommodated (Rodriguez *et al.,* 2004). These bags, which are filled, purged, and sealed at inland facilities, have the potential for use in identity preservation programs.

In recent years, the Argentine governmental agency, El Servicia Nacional de Sanidad y Calidad Agroalimentaria (SENASA), has developed quality standards for bread wheat and maize for the export market. Both wheat and maize are divided into three grades. Upon receival, elevator personnel perform initial assessment of grain. Moisture content is typically measured by capacitive instruments and protein content by NIR instruments. Lots that are determined to be of the highest grade (Grade 1) require no additional quality testing at receival (USDA-GIPSA, 2004a). Those determined to be in either of the two lower grades (Grades 2 and 3) are required to be evaluated by a non-profit inspection company (Camara Arbitral de Cereales, or CAC) at the expense of both buyer and seller. Only in rare circumstances, when disagreement of the CAC evaluation persists between buyer and seller, does SENASA step in for a final evaluation.

SENASA's inspection standards for grade are largely based on visual inspection of a representative sample. In addition to stated limits for test weight, the other grade-determining factors fall into the broad categories of foreign material, shrunken and broken kernels, and damaged kernels (Argentine Wheat, 2008). The latter category for wheat is divided into heated kernels, smut, yellow-berry, shrunken and broken, and insect-bored. Shrunken and broken kernels are defined as whole or pieces of kernels that pass through a sieve having 1.6 mm by 9.5 mm slots. Although protein content is not a grade-determining component, it is included in the standard to indicate whether the price of the wheat is increased (> 11.0% protein) or discounted (< 11.0% protein). Similarly, the standard includes the economic bonus or discount for wheat that is graded above or below the middle grade level (Grade 2). For the most recent year available (2006–2007), Grades 1 and 3 were 1.5% higher and 1.0% lower in respective value than the middle grade.

Grain at export terminals, such as in Rosario, is inspected by private surveying companies that are accredited by SENASA. The sampling and testing procedures are generally those of GAFTA (Grain and Feed Trade

Association, London, UK), though inspection equipment is not standardized. Interval sampling (4 intervals per 5000 tonnes, typically) of conveyor belts is performed and inspection is made on sample sub-lots typically representing 5000 tonnes, in which the sub-lots are checked for compliance to Argentine standards (USDA-GIPSA, 2004a). However, the government-sanctioned inspections are more for the purpose of ensuring sanitation and certifying tonnage than for quality assurance.

11.7 Traditional equipment used in wheat inspection at receival

Getting a representative sample of the grain lot is essential. Depending on the size of the grain receival facility, equipment can range from hand-held probes to programmable pneumatic samplers. Detailed discussion of sampling devices is beyond the scope of this chapter. However, common to all sampling plans is the need to ensure that the sample is representative of the lot or sub-lot from which it was drawn. For wheat in the United States, this typically entails gathering either a separate 2000 g work sample for every 500 bu (176 hL) sub-lot or, in the usual case of country elevator deliveries, a work sample that represents each truckload. The USDA-GIPSA sampling procedures are described in Section 11.7.1. Alternatively, the International Standards Organisation (ISO) has developed recommendations for static sampling from a wide range of storage and conveyance devices, including bags, wagons, and trucks (ISO 13690, 1999). For truckloads containing less than 15 tonnes of grain, five probe sites in a pattern are recommended. Similarly, ISO has developed a standard for automatic sampling by mechanical devices (ISO 6644, 2002), such as diverters, tubular samplers, and cup samplers. With these devices, the recommended collected amount is broadly specified as 5 kg for lots up to 500 tonnes.

11.7.1 Sampling devices

Probes are made of brass or aluminum consist of two tubes, one inside the other. Eleven to twelve regularly spaced compartment windows are placed along the 1.5–1.8 m length of the probe assembly. After insertion of the probe vertically in the truck, grain flows into the probe when the outer and inner tubes are twisted to align the windows. In the United States, recommendations exist for collecting a sample by probe. For a typical flat-bottom truck or trailer, the probe is inserted at three regularly spaced distances along the length of the truck and approximately 0.5 m from the inner wall of one side, with an emptying of the probe between insertions. Another three probings are made along the opposite side, as well as one in the center of the truck. Combined, the grain should total at least 2000 g. Additional probing may have to be made for loads that are suspected to be of inferior quality, in which case the new sites are staggered with respect to the original ones.

Diverters are mechanical samplers that are mounted near the stream of the grain exiting the truck, at the end of a conveyor belt, or at the head of an elevator leg. Periodically, the diverter, or 'pelican' (typically 1.9 × 2.2 cm opening) moves across the stream of grain at a typical speed of 0.5 m/s, capturing a small portion of grain. The cycle time or period of the diverter depends on the flowrate of the grain [for specifications, see USDA-GIPSA, 2003], but usually ranges between 12 and 72 seconds. A secondary stage within the sampler may be used to return a portion of the diverted grain back to the main stream. Sampling occurs throughout the duration of movement of the load, with a targeted sample mass of at least 2000 g.

Cups or 'pelicans' are manual sampling devices, known as an Ellis cup or a leather pelican pouch, that are placed in the stream of the moving grain. The sampler is required to periodically draw a set (equals three Ellis cupfuls or one 'pelican' cut) of grain from the stream every 500 bushels. For trucks, this translates into at least two sets, with a set typically representing 500 bushels. Similar to the other sampling devices, the amount of grain for inspection should be at least 2000 g.

11.7.2 Bulk density (test weight)

These devices consist of a cylinder of standard dimension that receives grain when filled and leveled in a manner prescribed by the standard and weighed, whereupon the bulk density is determined by direct reading from a dedicated weighing scale or by calculation. The precision of this procedure is highly dependent on the level of adherence to the filling and leveling steps. In the United States, test weight is reported in English units as the number of pounds per Winchester bushel, with values ranging from ≥ 60.0 for No. 1 Hard Red Winter to ≥ 51.0 for No. 5 grade of the same class. For Canada and elsewhere, test weight is reported on a kilogram per hectolitre basis, and uses a cylinder of 0.5 liter capacity typically (versus a one-quart kettle for US official analysis). Direct conversion between English and metric test weight values are to be made with caution due to the effects that container geometry and filling procedure have on the packing density of the kernels. For example, the USDA-GIPSA specifies the following conversion formula when changing non-durum type wheat from pounds per bushel to kilograms per hectolitre: kg/hl = lb/bu × 1.292 + 1.419 (USDA-GIPSA, 2004c).

11.7.3 Moisture content

Knowledge of grain moisture content is extremely important for reasons of avoiding spoilage from microbial activity (too much moisture), avoiding unsafe dust levels within the elevator (too little moisture), and having accurate knowledge of the concentrations of nutritional components of grain. Although moisture content is not generally a direct factor in determining wheat grade, there are requirements on the maximum moisture content allowed to avoid spoilage. Further, the concentrations of constituents such as protein content are adjusted to a fixed moisture level (e.g., for wheat: 12.0% in the United States, 13.5% in Canada, 0.0% in the EU). Because of this, moisture level can be a factor in calculating the sale price of the grain at receival. For grain that is traded on an 'as-is' weight basis, moisture content directly affects sale price of the lot. Most elevators use a capacitive type instrument, as described in Section 11.2.

11.7.4 Sieves and dockage tester

Essential to the determination of grain value is an accurate assessment of the amount of useable material within the lot compared to the total mass of material delivered. For wheat, this can be thought of as the amount of sound, mature, disease-free, undamaged millable kernels. By use of sieves, screens, and aspiration, either through manual or automated mechanical operations, such as the Carter dockage tester, the percentage of useable material is determined. For United States wheat, dockage becomes a factor in determining whether a lot is of sample grade. For the higher US grades, the percentage of dockage is reported on the grade certificate. For Canadian wheat, the amount of dockage serves as an estimation of the amount of material that must be removed by cleaning, because Canadian wheat for export must be 'commercially clean' of this type of material. Otherwise, Canadian wheat that is not commercially clean cannot be exported without special permission of the Canadian Grain Commission.

11.7.5 Protein content

Most elevators possess a near-infrared (NIR) instrument that is configured in one of two formats: reflectance measurement of ground meal (original method) or transmittance measurement of whole kernels in bulk (newer method). The latter method is often preferred because it does not require a sample to be ground and permits several hundred grams of grain to be analyzed, as opposed to ground meal reflectance instruments that necessitate the use of a divider to obtain a representative sample (20–50 g) for grinding, packing an optical cell, and clean-up of the cell afterward. Calibrations for protein content and other constituents of interest (e.g., moisture, oil) are often furnished by the instrument manufacturer or are developed and distributed by cooperatives or government offices. Nearly all NIR procedures are considered as secondary methods. Thus, a primary method, such as Kjeldahl or combustion for protein content, must be available at a central facility to keep a calibration in alignment through periodic checks. Because of the ease of use of NIR instruments, their accuracy (standard errors for protein content typically less than 0.20 percentage units when checked against the reference method) and rapidness (1–2 minutes per sample), this methodology for grain protein analysis has been adopted worldwide.

11.7.6 Wheat hardness

The texture or hardness of wheat endosperm is critical in determining the suitability of wheat for various end products. Historically, wheat hardness was evaluated by particle size index (PSI), defined as the weight portion of a sample of flour passing through a very fine (i.e., No. 200) sieve. Starting in the 1980s, NIR reflectance spectroscopy has been used to measure hardness, first as a method that correlated to the PSI method (Williams and Sobering, 1986), and later as a primary method (Norris *et al.*, 1989) approved by AACC International (Approved Method 39-70A, AACC, 2000). In the latter method, the NIR reflectance instrument must be calibrated using a set of ten reference material (RM) samples available from the US National Institute of Standards and Technology (NIST, RM 8441A). The basis for the NIR method lies in dependency of the intensity of diffusely reflected light on the flour particle size distribution. This indirect method of light scatter, calculated from a measurement of the responses at two wavelengths (1680 nm and 2230 nm) of nonspecific absorption, is effective in defining wheat hardness on a continuum scale, with hardness typically ranging from about 20 for the very soft wheats to 100 or slightly higher for durum wheats.

Starting in the early 1990s, an alternative method for wheat hardness was developed by the USDA-ARS in Manhattan, KS. An electrical/mechanical device, known as the single kernel characterization system (SKCS) was developed that measured: (a) the forces involved in crushing an individual kernel, (b) the size and mass of the kernel, and (c) its DC conductance (an indicator of moisture content), whereupon a hardness coefficient, based on a scale similar to that of NIR hardness, was calculated (Martin *et al.*, 1993). A minimum of 300 kernels are evaluated in order to characterize the distribution of kernel hardness of a sample. The technology for the SKCS was licensed to Perten instruments (Huddinge, Sweden) and the improved instrument (Model 4100) has been commercially available for several years. To date, the instrument has been acquired mainly by central government inspection laboratories and wheat breeding and genetics improvement laboratories. Cost and instrument complexity have precluded its wide adoption by wheat receival sites.

11.7.7 Enzyme-linked immunosorbent assay (ELISA) test kits for mycotoxins

The development of enzyme-linked immunosorbent assay (ELISA) test kits for cereals analysis has been underway for more than 20 years. The two most common applications are kits for mycotoxins (aflatoxin, deoxynivalenol, fumonisin, ochratoxin, T-2 toxin, and zearalenone) and transgenic maize varieties. Despite the widespread occurrence of *Fusarium* head blight in all regions of the world that produce wheat and barley, elevators generally do not routinely test for mycotoxin levels, such as deoxynivalenol (DON), unless there is a known problem in a particular crop season. Instead, operators will rely on the general appearance of the kernels in the work sample during visual inspection. In special circumstances, operators may use commercially available test kits for DON analysis in-house or may deliver samples to outside analytical laboratories on a fee basis. In the United States, the USDA-GIPSA's national center in Kansas City, MO will also conduct DON testing, either on a separate fee basis or as a non-grade determining criterion (similar to protein content) in an official inspection of wheat, barley, oats, and maize. GIPSA has an approval program for DON test kit manufacturers, for which 18 field test kits have been approved (USDA-GIPSA, 2008b). Similarly, GIPSA has conducted ELISA testing for the presence of transgenic maize, including screening for the patented (Aventis) variety 'StarLink', which possessed the *Bt* transgene (see Section 11.8.4) and received U.S. FDA approval for feed use but not for use in human foods; it was subsequently removed from the market in 2000. Because of the extremely low occurrences of StarLink today, it is likely that this form of testing will cease in the near future. ELISA testing is also conducted for aflatoxin in maize, which is mandatory in the United States for all exported maize.

11.7.8 Falling number

The processing quality of wheat and barley decline sharply with increased levels of enzymatic activity brought on by pre-harvest sprouting. All visual inspection procedures include cues for detection of sprouted kernels; however, the level of alpha-amylase activity may be very high even though the kernel has no outward appearance of sprouting. This condition almost always occurs during unfavorable weather conditions leading up to harvest. In circumstances when the elevator operator knows that such conditions have occurred, he may elect to test the wheat at receival. The two instruments available for indirectly testing alpha-amylase activity are the falling number (Hagberg) instrument and the Rapid Visco Analyser (RVA). In both methods, the starch within a meal-water mixture undergoes gelatinization during heating. The alpha-amylase catalyzes the hydrolysis of starch, which results in a reduction in starch paste viscosity. The older of the two methods, the falling number, simply reports the time needed for a machined stirring rod, including a 60-second period of up and down movement, to descend a fixed distance through a starch paste slurry contained in a precision test tube immersed in water at near boiling temperature. The RVA, developed in Australia in the 1980s, is a dedicated viscometer that tracks the torsional forces imparted on a paddle as it stirs a meal–water mixture at a prescribed rotational speed and heating regime. While the falling number procedure is more universally used, the

RVA may be better adapted to conditions where the abundance of water (as needed for the falling number instrument) is questionable.

Falling number tests at first point of sale, such as the elevator, are generally not performed unless there is reason to believe that wheat or barley from a particular region was subjected to wet weather prior to harvest. Though frequently required on export sales contracts, falling number is not a requirement for official inspection in some countries (e.g., Argentina, Canada and the United States), or it may supersede a count by visual assessment for percentage of sprouted kernels in other countries (e.g., Australia), with required minimum values ranging from 200 s to 350 s, depending on the grade. The EU regulations on qualifying grain lots for intervention agencies specifies a minimum falling number of 220 s for both durum and common wheat.

11.7.9 Human visual analysis

Visual inspection of the grain lot as a whole, as well as careful inspection of a representative sample, be it officially or unofficially, has been and will continue to be the overarching method of grain inspection at receival. Instruments such as digital imaging devices with pattern recognition algorithms have not been able to replace manual visual analysis. The reason for this lies in the diversity of conditions to be examined, which include broken and shriveled kernels, immature kernels, heat-damaged and frost-damaged kernels, staining, insect-damaged kernels, stored grain insects, ergot, mold-damaged kernels, foreign seeds, foreign matter, non-threshed grains, sprouted kernels, and kernels of other classes.

The ability to discern the particular damage condition or defect for official analyses requires an extensive training program, as well as a check system to ensure alignment of field offices. In the United States, as explained in Section 11.2, formal agreements exist between designated or delegated inspection offices and GIPSA field offices, and likewise between the field offices and the national laboratory, that specify the types and number of check samples exchanged. Similar mechanisms exist for the other grain-exporting countries. Additionally, Australian, Canadian, and American programs are reliant on a collection of digital images of normal, diseased, and defective grains that are used as references.

11.7.10 Near infrared (NIR) spectroscopy

Without question, NIR spectroscopy has been the most important 'breakthrough' in the last 50 years for rapid assessment of grain quality. Originating with the work of Karl Norris and co-workers of the USDA Agricultural Marketing Service (later with the USDA-ARS) in the 1950s, in which a rapid method was desired to monitor moisture gain and loss in five pound sacks of flour on the grocery shelf, this technology has evolved with the development of multivariate regression analysis methodologies. With thousands of applications published in journal articles, NIR technology is presently found in industries well beyond the cereals industry (e.g., petroleum, pharmaceutical, biomedical), though the food and feed industries are probably the ones that have most readily embraced it.

An explanation of the principles of NIR spectroscopy is the subject of numerous texts (Osborne *et al.*, 1993; Williams and Norris, 2001; Burns and Ciurzcak, 2001; Siesler *et al.*, 2002) and is therefore avoided in this chapter. NIR research on cereals was recently reviewed by Delwiche (2004). Therefore, this section is devoted to how NIR spectroscopy is utilized in grain quality programs, using the official program of the United States as an example. Details of this program are provided in USDA-GIPSA's Near-Infrared Transmittance Handbook (USDA-GIPSA, 2006b), which is available at the agency's website (http://www.gipsa.usda.gov). Through its field offices and approved agency offices, GIPSA maintains a network of more than 100 NIR instruments. Surrounding each of these offices are the country elevators and private analytical laboratories that unofficially (but legally) tie into the GIPSA network through the open access to the agency's calibration equations. According to the United States Grain Standards Act (Sections 800.125 and 800.135), the constituents of wheat, barley, maize, and soybean that are typically requested in sales contracts, namely contents of protein, oil (maize and soybean), and starch (maize only), are not considered as grade-determining factors, but rather as 'official criteria'. Nevertheless, these factors are commonly used in establishing price, thus making the need for their accurate measurement critical. Fortunately, NIR methodology is well suited for such measurements. Largely through consolidation of the NIR grain equipment manufacturers, one instrument series, the Foss Infratec Grain Analyzer (Hillerød, Denmark), has become the de facto standard whole grain instrument in the United States and elsewhere throughout the world. The instrument is a dispersive-type monochromator that measures transmitted energy (850–1050 nm wavelength region, 100 readings in all) through successive columns of grain within its chamber, applies an internally stored calibration vector equation to the readings, and displays the average predicted constituent value. Essential to the accuracy and precision of the NIR instrument are: (1) the diversity of the set of samples used in development of the calibration, (2) the accuracy of the primary reference method, (3) the stability of the NIR instrument, and (4) the consistency of the operator in loading and operating the instrument. Generally, the first two requirements are the domain of a central laboratory, such as GIPSA's national center in Kansas City. Because of the 15+ years of sampling and calibration development and the fact that primary methods such as combustion protein analysis are highly precise [RSD < 1% (Bicsak, 1993)], central control of the first two requirements is well in order. For the remaining requirements, GIPSA monitors the instruments in its field offices and designated agencies by requiring that samples be submitted on a weekly basis to its central laboratory in Kansas

City, MO. Typically, this consists of five samples for each grain species that is being inspected during that period, with two of the samples being the lowest and highest values encountered. These samples are then evaluated on a master instrument at the central office. Control charts are made that track the five-sample average difference between field and master instruments, as well as one that tracks the range difference (sample with greatest positive difference minus sample with most negative difference). Tolerance limits are prescribed for three conditions: (1) the average or range difference for the given week exceeding an 'absolute limit', (2) the differences for the given week and the preceding week exceeding a 'tolerance limit', and (3) the differences for four of five consecutive weeks exceeding a 'run limit'. When any of these limits are exceeded, corrective action must be taken immediately.

Additionally, each remote office performs a daily check of the NIR calibration for each commodity and constituent that it intends to analyze. This consists of running a set (i.e., standard reference set) of four to six check samples distributed by the central laboratory. Tolerance levels must be met for the constituent of interest, either on the basis of a single run's deviation from the established (baseline) value, the difference between duplicate runs, or the average deviation when all runs and duplicates are combined. Taking wheat protein content as an example, these levels are ±0.40%, ±0.20%, and ±0.10% for the single run deviation, duplicate difference, and combination deviation, respectively. Additional restrictions are placed on the deviations when compared to those of daily checks of the preceding two weeks (see GIPSA NIRT handbook). When a tolerance level is exceeded, a 'bias' correction is made to the constant term in the calibration equation by subtraction of the combination deviation.

11.8 New technologies for use at grain receival

Current practices of grain inspection at receival continue to be heavily reliant on human visual analysis. To alleviate the time and labor demands that inspection requires, research has been active in the development of objective techniques that assist or replace traditional inspection operations. Underlying the successful adoption of these techniques at the country elevator will be the need for ruggedness, reliability, simplicity in use, speed, and accuracy. NIR spectroscopy, first introduced to the grain industry in the 1970s, is probably the best example of a technology that transformed the grain trade. NIR whole kernel transmittance is now used extensively in the measurement of protein content in wheat in national inspection programs, as well as in commerce. New technologies are sought with the same potential for adoption at receival sites as NIR spectroscopy. The technologies of active research are described in the following paragraphs.

11.8.1 Digital imaging

Research on image analysis of grains dates back more than 20 years. Early research by the USDA-ARS in Manhattan, Kansas in the 1980s dealt with the identification of kernel morphological (size and shape) features that could be used to discriminate between the US wheat classes (Zayas *et al.*, 1986), particularly during a time when a soft red winter wheat variety, 'Arkan', which had the appearance of a hard red winter wheat, was released and caused confusion in the wheat trade industry (Zayas *et al.*, 1985). Similar work on classification was underway in Canada (Sapirstein *et al.*, 1987; Symons and Fulcher, 1988), with the use of color analysis soon following (Neuman *et al.*, 1989a, 1989b). The early work on grain imaging is reviewed in Sapirstein (1995). Since then, research has advanced into the detection of molds (Ruan *et al.*, 1998, Luo *et al.*, 1999), image processing of touching kernels (Shatadal *et al.*, 1995), kernel texture (Majumdar and Jayas, 2000), and kernel vitreosity (Xie *et al.*, 2004). Inspection of brown rice has benefited from the combination of morphological feature extraction, color reflectance, and attenuation of transmitted light through single kernels in a dual camera system that is capable of sorting rice into thirteen quality states (Wan *et al.*, 2002).

Commercial imaging instruments dedicated to grain inspection have been developed during the past ten years, mainly by two companies. The Acurum® system, developed by DuPont Canada uses a color CCD camera and a conveyor belt operating at 2.5 frames per second, with approximately 40 kernels per frame, to examine wheat for a specific condition. The best application for the Acurum instrument has been in detecting the non-vitreous starchy region in durum kernels (necessary in determining the percentage of hard vitreous kernels for grade assignment), using a cascade of logic statements. At the time of this writing, DuPont is seeking to sell its Acurum technology. The Cervitec® system of Foss (Hillerød, Denmark), either dedicated to rice inspection (Model 1625) or wheat and barley inspection (Model 1642), is also a color-imaging system that can process approximately 1000 rice kernels per minute or 700 wheat kernels per minute. The system is trained to detect the condition(s) of interest using artificial neural network algorithms.

11.8.2 Hyperspectral imaging

Recent research has attempted to exploit the combination of NIR spectroscopy and digital imaging. Known as hyperspectral image analysis, spectral readings, typically in the visible to the short wavelength region of the near-IR (400–1100 nm) are collected at every pixel within the image. Although this places a much larger demand on computer storage and processing, the hyperspectral image holds the promise of advantages in the detection of subtle changes along the kernel surface undetectable by visual analysis through the simultaneous processing of images at more than one wavelength. To date, applications of this technology on cereals include detection of *Fusarium*-damaged wheat kernels (Delwiche and Kim, 2000), constituent analysis in maize kernels (Cogdill *et al.*, 2004), differentiation of mold species (*Penicillium, Aspergillus,* and *Fusarium*) in fungal-infected wheat kernels (Singh *et al.*, 2007), wheat kernel discoloration (black point, field fungi, or pink stain) of Australian wheat kernels (Berman *et al.*, 2007), and detection of hard vitreous kernels in durum wheat (Shahin and Symons, 2008). Equipment expense, complexity of analysis, and slowness are obstacles to the installation of this technology in the grain elevator. However, the research gleaned from hyperspectral imaging may result in the development of simpler one-to-three wavelength multispectral systems that would be less expensive and fast enough for receival inspection operations.

11.8.3 ELISA test kits for insect activity

In addition to mycotoxin and transgenic variety testing by ELISA (see Section 11.7.7), researchers have explored the assessment of stored insect contamination. As an alternative to manual counting of insect fragments in the filter residue of acid-hydrolyzed flour [with a US Food and Drug Administration (FDA) action level limit set at 75 fragments per 50 g flour (US Food and Drug Administration, 1988)], an immunoassay technique was developed for quantifying the level of stored grain insects, based on its sensitivity to myosin (Kitto, 1991). A collaborative laboratory study was conducted that compared this technique with other insect detection methods (X-ray analysis, cracking and flotation, and insect fragment count), with results indicating that the ELISA technique had the highest precision (Brader *et al.*, 2002). Recent research has indicated that the concentration of detectable myosin declines with storage (for instance, after fumigation), such that the ELISA procedure may underestimate the level of insect infestation (Atui *et al.*, 2007). Other research on the red flour beetle (*Tribolium castaneum*) has demonstrated the ability of immunoassay techniques to detect stored grain insect contamination even after removal of the insects and larvae due to a sensitivity to fecal matter (Krizkova-Kudlikova and Hubert, 2008). Despite the commercial release of an ELISA test kit (Biotect®, Austin, TX) for insect contamination, there has been reluctance on the part of the grain industry to adopt this method.

11.8.4 Polymerase chain reaction (PCR)-based detection methods

Methods that rely on DNA-based polymerase chain reaction (PCR) procedures are becoming more commonplace in the cereals industry, particularly for the detection or quantification of GMOs. The common example for this lies with maize that has been genetically modified to contain a gene from the soil microbe *Bacillus thuringiensis* (*Bt*) which codes for the production of a toxin that is effective in control of the European corn borer (*Ostrinia nubilalis*) (Pan *et al.*, 2005; Zhu *et al.*, 2008). For many grain-importing countries, especially those of the European Union, strict limits (0.9% per ingredient in the EU) are imposed on the level and traceability of GM contamination in final food and feed products (European Commission, 2003a,b). Similar restrictions are placed on food products containing GMO soymeal that contains the 'Roundup Ready' transgene, a modification that enables the plant to be resistant to the common herbicide, glyphosate. Although the PCR method is very effective in GMO detection, equipment and operational expenses are high, and the required level of operator training is much higher than protein-based methods such as ELISA (Holst-Jensen *et al.*, 2003). Use of PCR methods, therefore, is unlikely at the country elevator.

11.8.5 Electronic noses

One component of the inspection process is the evaluation of the headspace above the grain for presence of off odors caused by molds, insects, straw, herbs and other non-grain species, insects, decay, and odors from other contamination sources. Reliance on the human nose for inspection has the drawback of disagreement among individual inspectors' perceptions of odors, as well as a health risk associated with the inhalation of the spores and vapors arising from the grain sample (Olsson *et al.*, 2002). The electronic nose typically consists of several metal oxide semiconductor field effect transistors (MOSFETs) that are sensitive to the volatiles in the headspace during a regiment of warming (~50 °C) the sample. Multivariate calibrations, such as principal components analysis and partial least squares regression (Olsson *et al.*, 2002) or artificial neural networks (Börjesson *et al.*, 1996; Jonsson *et al.*, 1997) are used to relate the time response data from the detectors to a class of odor or a concentration of a compound, such as deoxynivalenol. Two commercial manufacturers of electronic noses that have applications in cereals are known: Alpha MOS (Toulouse, France; three models, with 6, 12, or 18 sensors) and Electronic Sensor Technology (Newbury Park, CA, USA; four models in portable or benchtop configurations). Although the application of the electronic nose for grain inspection was investigated by the USDA-GIPSA in the 1990s, this technology has not been implemented in field offices or country elevators, presumably for the reasons of complexity of operation and instrument cost.

11.8.6 X-ray imaging for internal insects

Research on the use of x-rays to detect insect eggs and larvae within the kernel has been ongoing for more than 50 years (Milner *et al.*, 1950; Stermer, 1972; Schatzki and Fine, 1988; Keagy and Schatzki, 1993). Though x-ray analysis is useful in detection of the pre-adult stages of stored grain insects, the procedure of producing images on photographic film has been a detriment to rapid analysis. Advances in digital imaging technology now make it possible to capture and store the images without the need for film, whereupon the images can be viewed by the inspector (Haff and Slaughter, 2004), or image processing classification algorithms may be applied for unattended determination of internal infestation (Karunakaran *et al.*, 2003). Again, the complexity and cost of the equipment will be an obstacle to the adoption of X-ray imaging to all but the largest elevators and terminals.

11.9 Future trends

Assessment of grain quality, particularly at the first point of sale, continues to be heavily reliant on manual inspection. The reason for this is largely because of the complexity of the inspection itself. In the case of wheat, this involves the need to determine various conditions of kernel damage and contaminants, which surprisingly have a high degree of commonality among the major exporting countries (Table 11.6). Today, instrumentation exists that can accurately measure concentrations of contaminants, biochemically related quality properties (protein, starch and oil), physical properties, odors, insect infestation and defects. Unfortunately, there is no single instrument capable of performing all quality monitoring tasks. Thus, a suite of instruments would be needed to replace the human inspector. This is unlikely due to the excessive cost of all equipment.

In lieu of relying on an arsenal of equipment, country elevators will continue to use the combination of manual inspection and, depending on the growing region, instruments specific to anticipated conditions of that region. For example, falling number analysis may be conducted in areas known to have had rainy conditions prior to harvest. In the opinion of the author, digital image analysis may eventually become an integral part of the cereals inspection process. Despite the fact that image-based inspection systems have been available for more than ten years, their implementation at the country elevator never caught on. This may change as the use of digital cameras becomes universal. However, rather than relying on a trained and fully automated system, newer imaging devices will be used probably as tools for the elevator personnel. In addition to assessing the quality of a grain lot, the new system will benefit by allowing for the indefinite storage of the sample images well beyond the one-week to several-month time periods that reserve samples are normally held. Lastly, as analysis times for ELISA test kits for mycotoxins and GMOs become of the order of minutes, the use of these kits at first point of sale will most likely rise.

11.10 Sources of further information and advice

The following web sites provide extensive information on how cereal quality is assessed in the world's major grain exporting countries. Additionally, many provide crop-quality survey reports that are updated annually.

Table 11.6 Summary of wheat grade factors of the major wheat exporting countries

Quality parameter	Argentina	Australia	Canada	European Union		France	United Kingdom	United States
Test Variety	Grade No. 1	APH2	No. 1 CWRS	Durum	Common Wheat	Class E Wheat	UKP Bread Wheat	US No. 1 HRS
Protein content	√	√	√	√	√	√	√	
Test weight	√	√	√	√	√	√	√	√
Falling number		√		√	√	√	√	
Moisture	√	√		√	√	√	√	√
Zeleny index				√	√	√		
Wet gluten	√					√	√	
Alveograph	√					√	√	
Farinograph	√					√		
Mixograph								
Ash	√						√	
Weight of 1000 kernels	√							
Odor		√	√				√	√
Hardness			√			√	√	
Baking test		√						
Milling		√						
Sampling								
Size before splitting	4 kg	> 3 L	900 g					1000 g
Size after splitting			>250 g					250 g, 15 g
First cleaned by: (1) Dockage tester			√					√
(2) Sieve	√						√	√
(3) Other		√						
Defects/Damage								
Heat damage	√	√	√	√	√		√	√
Shrunken and broken kernels	√		√	√	√		√	√
Sprouted	√	√	√	√	√	√	√	√

Stained		√	√			√	√	
Fusarium damage		√	√	√		√	√	√
Smut	√	√	√	√	√			
Insect-damage	√						√	√
Chaff							√	√
Frost	√		√					√
Germ	√		√				√	√
Mold			√				√	√
Green or sappy	√		√					
Non vitreous		√				√		
Darkened kernels			√			√		
Spotted				√		√		
Total damage	√	√	√	√	√	√	√	√
Contaminants								
Dead insects	√	√	√				√	√
Live insects	√	√	√				√	√
Ergot		√	√	√	√	√	√	√
Excreta		√	√				√	√
Stones		√	√				√	√
Other grain seeds		√	√	√			√	√
Other seeds	√	√	√	√	√		√	√
Other foreign material	√	√	√	√	√	√	√	√

http://www.fsa.usda.gov/FSA/webapp?area=home&subject=coop&topic=was – USDA Farm Service Agency, Commodity Operations, Warehouse Services – information about licensing of grain elevators and their locations.

http://www.gipsa.usda.gov – USDA Grain Inspection, Packers and Stockyards Administration – information on US grain standards and standard operating procedures.

http://www.awb.com.au – Australian Wheat Board – formerly, the sole exporter of Australian wheat and developer of wheat standards for that country.

http://www.graintrade.org.au – Grade Trade Australia (formerly National Agricultural Commodities Marketing Association, or NACMA) – the keeper of Australia's grain standards.

http://www.sagpya.gov.ar – Argentina's Ministry of Agriculture, Livestock, Fisheries and Food (in Spanish).

http://www.inta.gov.ar – Argentina's National Institute of Agricultural Technology, the government's agricultural research and extension organization (in Spanish).

http://www.trigoargentino.com.ar – Commercial clearing house that releases a yearly quality report of Argentine wheat.

http://www.arvalisinstitutduvegetal.fr/en/ – A private technical institute that deals with arable crops in France, including cereals, from production through first processing. Release yearly quality reports on French wheat (in French).

http://www.uswheat.org – US Wheat Associates – a private organization that promotes the export of US wheat. Maintains downloadable yearly crop-quality reports for several wheat classes.

http://www.hgca.com – Home Grown Cereals Authority – a private organization that provides market information, funds research, and promotes the export of UK cereals and oilseeds.

http://eur-lex.europa.eu/en/index.htm – Portal to European Union law.

http://www.cwb.ca – Canadian Wheat Board – a private marketing agency that promotes domestic and export sales of Canadian wheat.

http://www.grainscanada.gc.ca – Canadian Grain Commission – a government agency that establishes grain standards and conducts inspections and research.

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